Enhancement of Vegetable Crop Growth with Biosolids and Yard-Waste Compost on a Calcareous Clay Soil

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ABSTRACT

Research is needed to determine if organic matter residuals available near urban centers will benefit vegetable crops when incorporated into calcareous clay soil common to the Southern Great Plains of the United States. Therefore, a field plot study was conducted on a Houston Black clay in north Texas where organic matter amendments were incorporated into the soil in the late summer of 2001 and the early fall of 2002. Cumulative application rates for the two years were 26 tons ac^{-1} for waste water residuals (biosolids) and 31 or 93 tons ac^{-1} for a low and high rate of municipal yard waste compost (MYWC), respectively. An untreated check that received no chemical fertilizer treatment was included as a control. The sequence of crops consisted of soybean (spring-summer 2002), turnip and beet (fall-winter 2003), and sweet corn (spring 2003). The yield of the edible portion of all four crops increased when soil was treated with biosolids as compared to untreated soil and was followed in rank by the high rate of MYWC, the low rate of MYWC, and finally the check. These findings suggest that biosolids and MYWC applied to this clay soil has yield-enhancing potential worth further investigation.

KEY WORDS: fertility, root-to-shoot ratio, soil amendment, yield

INTRODUCTION

Home gardeners in several urban areas of the southwest USA are forced to deal with heavy clay soils that are highly calcareous and serve as a poor media to raise vegetables. Numerous soil amendments are available to improve the tilth of these soils but how these amendments affect vegetable crop productivity remains uncharacterized. Logan et al. (1997) reported that yield of six vegetable crops were similar when grown after soil was amended with biosolids as compared to control plots. In Iowa, Delate (2002) reported that yield of corn (*Zea mays* L.) grown using conventional practices during a three-year study was numerically higher (118 - 142 bu ac^{-1}) compared to corn raised organically (102 - 121 bu ac^{-1}). In contrast, soybean yield was similar (31 – 42 bu ac^{-1}) between the two production methods. Ozores-Hampton and Peach (2002) recently reviewed the production of biosolids, rules regulating their application to vegetable crops, and their general effects on vegetable production. In their report, biosolids applied to a calcareous soil at rates up to 10 tons acre^{-1} were shown to increase yield of several vegetable crops.

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Numerous other soil amendments have been tested on vegetable crops. Hunter et al. (1995) reported green manure from cowpea (*Vigna unguiculata*) at rates of 3.4 and 6.7 tons ac^{-1} incorporated into the soil led to sweet corn yield equal to that of soil receiving 45 lbs ac^{-1} each of N, P, and K. Roe et al. (1997) found specific mixtures of biosolid-yard waste compost and synthetic fertilizer to increase vegetable crop yield. Duval et al. (1998) compared the yield of turnip (*Brassica rapa* L.) and mustard greens (*Brassica hirta* L.) when soils were treated with leonardite (a product containing 80% humic acid that is also high in Ca, Na, Mg, Fe, and S) or conventional fertilizer but did not find any growth differences. Warman (1995) reported that soil treated with dairy manure compost at rates of 0, 10.1, 20.2, 40.6 and 81.3 tons ac^{-1} did not affect sweet corn yields but did increase soil moisture and soil N, P, K, and Mg availability. Wu et al. (1993) demonstrated that sweet corn yields from N, P, and K fertilizer (at 134, 58, and 58 lbs ac^{-1}, respectively) were significantly higher than three treatments containing only two of these elements and the untreated check. Additionally, all fertilized plots out-yielded the untreated check.

Addition of biosolids to vegetable crops raises the concern that the edible portion of the plants may contain unhealthy levels of heavy metals for human consumption. However, Dixon et al. (1995) demonstrated that uptake of metals such as Pb, Zn, Cu, Ni, and Cd by plants grown in a biosolids-treated area was less than control plots possibly because the increased pH of the biosolids-treated soil reduced the availability of these metals. Meanwhile, Warman et al. (1995) exposed beet (*Beta vulgaris*) plants to varying rates of compost/biosolids that was high in heavy metal concentration. However, the heavy metal concentrations of the beet tissue were only slightly increased as the compost/biosolids rate increased.

It is logical to suspect that each production region will need to test various soil amendments with its own soil types and in response to its own weather conditions. Therefore, the objective of this study was to quantify growth of selected vegetable crops grown in north Texas on a calcareous soil treated with biosolids or MYWC during a two-year period.

MATERIALS AND METHODS

Plot Layout. Experimental plots consisted of four replicate rectangular areas, each surrounded by two layers of 4 in diameter landscape timbers (Home Depot, Richardson, TX) laid flat at soil level to contain the soil and the amendments. The east and west sides of each replicate were 43.3 ft long and the north and south sides were 7.9 ft wide. Each replicate was divided into four plots measuring 7.9 ft by 7.9 ft (62.4 ft^2) separated by a 3.9 ft by 7.9 ft buffer area of soil that was planted but otherwise left untreated. The two end plots of each replicate terminated on one side at the landscape timbers and were only bordered by the buffer area on the opposite side. Replicates were separated by a 40-in walkway composed of weed cloth covered with 2 in of small red gravel.

Organic Matter Treatments. A Houston Black clay soil was treated with selected soil amendments (MYWC and biosolids) in the late summer of 2001 and in the fall of 2002. The MYWC was found to contain a relatively high concentration of K whereas the biosolids had elevated concentrations of N, P, Cu and Zn (Table 1). The soil organic matter treatments and their cumulative application rates were (1) an untreated control, (2) a low level (30.8 tons ac^{-1}) of municipal yard waste compost (designated MYWC-Low), (3) a high level (92.5 tons ac^{-1}) of MYWC (MYWC-High), and (4) waste water biosolids at 25.9 tons ac^{-1} (Table 2). We did not include a chemical fertilizer control because our long-term goal is to keep the entire area free from synthetic fertilizers and pesticides. Organic matter applications supplied a considerable amount of plant available N to the soil assuming an annual mineralization rate of 20% for compost and 30% for biosolids (Table 2). The experiment used a Latin square design with four replications. Treatments were surface applied on 18 Sept. 2001 and again on 17 Oct. 2002. All plots, including the untreated control, were cultivated with a motorized, walk-behind garden tiller immediately after surface application of the amendments.

Table 1. Properties and composition of the municipal yard waste compost (MYWC) and biosolids applied in 2001 and 2002.

	MYWC		Biosolids	
Property or Element	2001	2002	2001	2002
Organic Matter (%)	35.7	42.5	41.8	47.3
pH	7.63	7.95	9.68	9.56
Electrical Conductivity (μS cm^{-1})	2.06	1.50	5.80	8.71
Total N (%)	1.28	1.01	3.08	3.50
P (%)	0.189	0.214	0.865	1.22
K (%)	0.329	0.380	0.064	0.070
Mg (%)	0.374	0.369	0.290	0.427
Cu (ppm)	12	29	135	182
Zn (ppm)	62	101	455	358

Table 2. Annual and cumulative organic matter application rates for the low and high rates of municipal yard waste compost (MYWC) and the single application rate of waste water biosolids.

	2001		2002		Cumulative	
Organic matter amendment	Application rate (dry wt.)	Plant available N †	Application rate (dry wt.)	Plant available N	Application rate (dry wt.)	Plant available N
	tons/ac	lbs/ac	tons/ac	lbs/ac	tons/ac	lbs/ac
MYWC – Low	11.6	77	19.2	81	30.8	158
MYWC – High	34.9	230	57.6	242	92.5	472
Biosolids	14.3	297	11.6	264	25.9	561

†Plant available N (supplied by the supplements) assuming an annual mineralization rate of 20% for compost and 30% for biosolids from the organic N component. Values include inorganic N present in the amendments. Prior to planting soybean, nitrate-N level was 11 ppm.

Crop Sequence. Annual cereal rye (*Secale cereale*, cv. Elbon) was planted in the fall of 2001 following the first organic matter applications. In the spring of 2002, the rye was cut and incorporated in the soil. On 15 May 2002, vegetable soybean (*Glycine max* L. Merr., cv. Envy, Maturity Group III) seed was inoculated with Cell-Tech 2000 liquid *Bradyrhizobium japonicum* and then hand planted at 3.4 seed ft^{-2} (or 148,000 seed per acre) using six rows (running north and south) spaced 14 in apart. On 11 July, three leaves per plot (3rd uppermost fully expanded trifoliolate) were harvested to determine relative water content using the equation (fresh weight – dry weight) / (turgid weight – dry weight). On 15 July (growth stage R6, Fehr and Caviness 1977), plant height and main stem node number were determined from five plants per plot and then 3.3 ft of plants (including roots) were harvested from the two center rows (rows 3 and 4) and divided into seed, carpels, leaves, stalk (stems and petioles), roots, and nodules. The number of plants, pods, seeds, and nodules were counted and fresh mass of pods and nodules were obtained. All plant parts were dried at 158°F until constant weight for dry matter determination. On 26 July 2002, 3.3 ft of two of the four remaining rows (rows 2 and 5) were harvested for mature seed yield. These two rows harvested at R8 were unbordered on one of their three sides but all plots were treated equally and the unbordered situation was only 11 days in duration. After the R8 harvest, all seed and stalks were harvested and removed from the site. The second soil amendment application was applied several weeks later (Table 2).

On 17 October 2002, half of each plot was sown to beet (cv. Early Wonder Tall Top) and the other half was sown to turnip (cv. Purple Top White Globe). Row spacing was 14 in and the seeding rate was approximately 16 seed ft^{-2} (697,000 seed ac^{-1}). Consequently, each species was grown in a three-row subplot with rows running north and south. In early December, plots were thinned to approximately 6.5 plants ft^{-2}. On 15 Jan. 2003, 3.3 ft of bordered row was harvested from each species and plot. Plants were divided into roots and leaves for fresh and dry weight determination.

In April 2003, sweet corn (cv. TenderTreat) seed was sown in all plots using a 21-in row spacing with four rows (that ran north to south) in each plot. Seeding rate was approximately 1.4 seed ft^{-2} (61,000 seed per ac^{-1}) but plots were thinned to 1 plant ft^{-2} after three weeks. In mid-July 2003, the entire above-ground portion of the plants was harvested from 3.3 ft sections of the center two rows of each plot and separated into ears, leaves, and stalks. Ears were weighed fresh with and without husks. Dry weight on all parts was recorded as described earlier for the other crops.

Other Experimental Concerns. When planting for each crop, seed were sown in all buffer areas at identical seeding rates and row spacings as the treated areas. All crops were watered as needed and an organically-classified pesticide was applied only once when a solution of spinosad at 0.3 lbs per 100 gallons of water (0.4 g L^{-1}) was sprayed on sweet corn ears to runoff just after silk emergence with a single-wand hand-pump sprayer. The statistical analysis consisted of Proc ANOVA using SAS. Sources of variation were row (i.e., replicate), column, and treatment. Means were separated using LSD calculated using the error mean square and the t-value with 6 degrees of freedom.

RESULTS

Relative water content of soybean leaves averaged 0.76 and was not different among treatments (data not shown). Likewise, the number of main stem nodes averaged 8.8 and was not different among treatments (data not shown). Fresh and dry vegetable soybean seed yield at growth stage R6 increased as a result of the biosolids and MYWC-High application above that of the MYWC-Low and the untreated control (Table 3). The same was true of the total aboveground biomass. At final maturity, growth stage R8, seed yield of the biosolids treatment was greater than the other three treatments. Fresh and dry seed weight at R6 were correlated with plant available N (r=0.987* and r=0.997**, respectively.)

Table 3. Effect of soil-applied municipal yard-waste compost (MYWC) at two rates or soil-applied biosolids at one rate on the growth and seed yield of 'Envy' vegetable soybean grown on a Houston Black clay from 15 May to mid July 2002 near Dallas, TX. The growth stage R6 harvest occurred on 15 to 19 July and R8 was reached on 26 July 2002.

	Seed yield			Total biomass
Treatment	Fresh at R6 †	Dry at R6 ‡	Dry at R8 §	Dry at R6 ¶
	-------------------------- lbs ac^{-1} --------------------------			
Check	2370	679	1710	2870
MYWC - Low #	2790	804	1500	3180
MYWC - High	3870	1170	2010	4210
Biosolids	3960	1280	2420	4070
LSD (0.05)	486	220	328	835

† R6 indicates green pods were fully expanded and the seed filled the pod cavity. Seed were weighed immediately after shelling.

‡ Same as above (†) except the seed were weighed after oven drying at 140°F for three days.

§ R8, growth stage at which all pods were brown.

¶ The total biomass includes the roots and nodules.

MYWC (Low), MYWC (High), and Biosolids were applied at 11.6 tons ac^{-1}, 34.9 tons ac^{-1}, and 14.3 tons ac^{-1}, respectively.

The biosolids-induced soybean seed yield increase was associated with greater shoot-to-root ratio, a greater harvest index, and with increased aboveground biomass production (Table 4). Since seed size at R6 averaged 0.20 lbs per 100 seed (89 mg per seed) and was not different among treatments (data not shown), the yield component most closely associated with seed yield was seed number. Biosolids inhibited development of nodules whereas nodules were prominent on roots of the other three treatments.

Table 4. Effect of soil-applied municipal yard-waste compost (MYWC) at two rates or soil-applied biosolids at one rate on the harvest index, nodule biomass, shoot:root ratio, seed number, and plant height of 'Envy' vegetable soybean grown on a Houston Black clay from 15 May to mid July 2002 near Dallas, TX. The growth stage R6 harvest occurred on 15 to 19 July and R8 was reached on 26 July 2002.

Treatment	Harvest index	Nodule biomass		Shoot: root ratio	Number of seed at R6	Plant height
		Fresh	Dry			
		---- lbs ac^{-1} ----			no. ft^{-2}	in.
Check	0.23	149	38	9.1	90	14
MYWC - Low †	0.26	183	43	9.8	108	14
MYWC - High	0.27	132	34	11.0	135	16
Biosolids	0.31	12	4	16.8	141	12
LSD (0.05)	0.03	116	27	2.0	32	ns ‡

† MYWC (Low), MYWC (High), and Biosolids were applied at 11.6 tons ac^{-1}, 34.9 tons ac^{-1}, and 14.3 tons ac^{-1}, respectively.

‡ ns indicates that the treatments were not different statistically.

Except for turnip shoot mass of MYWC-High vs. MYWC-Low, beet and turnip dry matter yields (both shoot and root) were increased by biosolids and by MYWC-High (Table 5). Biosolids increased absolute shoot growth to a greater extent than root growth for both of these root crops. However, the shoot:root ratios (dry weight) averaged 3.23 for beet and 1.34 for turnip and were not significantly different among treatments (data not shown). Turnip root yield was correlated with plant available N (r=0.95*).

Table 5. Effect of soil-applied municipal yard-waste compost (MYWC) at two rates or soil-applied biosolids at one rate on dry shoot, dry root, and total dry biomass yield of "Early Wonder Tall Top' beet or 'Purple Top White Globe' turnip and grown on a Houston Black clay from November 2002 to January 2003 near Dallas, TX. Application rates listed refer only to the 17 Oct. 2002 application. Cumulative soil amendment rates are listed in Table 2.

Crop	Treatment	Shoot yield	Root yield	Total yield
		-----------	lbs ac^{-1}	-----------
Beet	Check	277	69	345
	MYWC - Low at 19.3 tons ac^{-1}	326	104	430
	MYWC - High at 57.8 tons ac^{-1}	503	187	689
	Biosolids at 11.6 tons ac^{-1}	1205	357	1560
	LSD (0.05)	145	49	179
Turnip	Check	930	708†	1640
	MYWC - Low at 19.3 tons ac^{-1}	978	743	1720
	MYWC - High at 57.8 tons ac^{-1}	1335	1200	2535
	Biosolids at 11.6 tons ac^{-1}	2670	1680	4350
	LSD (0.05)	363	388	699

† Fresh root yields for turnip were 1.91, 1.96, 3.35, and 5.31 tons ac^{-1} for the Check, MYWC-Low, MYWC-High, and Biosolids, respectively (LSD = 1.35).

Sweet corn ear yield (both fresh and dry weight) and leaf biomass were increased by biosolids but not by MYWC-High or MYWC-Low (Table 6). The ear yield increase of the biosolids treatment was greatly attributed to an increase in harvest index and to a lesser extent by overall growth. The yield component most closely associated with the difference between the biosolids treatment and the untreated check treatment was dry weight per ear (0.36 oz. dry weight vs. 0.12 oz. dry weight or 10.2 g vs. 3.56 g) whereas the number of ears was extremely variable. The low ear weight for plants grown on the untreated plots suggests an N deficiency, an expected outcome for corn. Based on the plant available N supplied by the biosolids amendments (Table 2), N was probably not limiting for the biosolids treatment even though the corn crop was preceded by a beet and turnip crop following the second annual application of the organic matter amendments.

Table 6. Effect of soil-applied compost at two rates or soil-applied biosolids at one rate on yield and biomass traits of sweet corn (cv. TenderTreat) grown on a Houston Black clay from April 2003 to July 2003 near Dallas. Application rates listed refer only to the 17 Oct. 2002 application. Cumulative rates are listed in Table 1.

Treatment	Ears	Biomass					Harvest index †
		Fresh ear	Dry ear	Dry stalk	Dry leaf	Dry total	
	no. ft^{-2}	-------------------		tons ac^{-1}	-------------		
Check	1.07	1.21	0.18	0.97	0.50	1.65	0.11
MYWC - Low ‡	0.99	1.76	0.28	1.08	0.50	1.96	0.15
MYWC - High	0.98	2.06	0.40	1.17	0.64	2.21	0.17
Biosolids	1.44	3.61	0.70	1.23	0.97	2.92	0.23
LSD (0.05)	ns	1.49	0.31	ns	0.27	0.91	0.07

† Harvest index = dry ear weight / total above-ground dry weight.
‡ MYWC (Low), MYWC (High), and Biosolids applied at 19.3 tons ac^{-1}, 57.8 tons ac^{-1}, and at 11.6 tons ac^{-1}, respectively.

DISCUSSION

The yield responses found on our calcareous clay soil support the findings of several other labs that researched biosolids applied to other soil media. Perez-Murcia (2006) found that a peat mixture with 30% composted sewage sludge (CSS) increased broccoli (*Brassica oleracea*) growth above that of mixtures containing 0, 15, or 50% (CSS). Ozores-Hampton et al. (1999) found that a yard-trimmings-biosolids co-compost stimulated tomato (*Lycopersicon esculentum* Mill.) seedling growth.

Preparation methods of biosolids and MWYC may also play a role in the release of N and their ultimate effects on plant growth. Sloan and Basta (1995) found that lime-stabilized biosolids, similar to the biosolids used in this study, increased soil solution NO_3-N concentrations over time to a greater extent than more stable forms of wastewater biosolids. Claassen and Carey (2004) found that poorly-cured MYWC initially immobilized soil N for up to 16 months before becoming a net positive source of mineralized N. However, the relatively quick response to biosolids reported in the current study contrasts with the slower response found by Hemphill et al. (1982). In that report, the first three years of sweet corn yields from $(NH_4)_2SO_4$-treated soil was greater than or equal to yields obtained from sewage sludge-treated soil. However, in the seventh year of that same experiment, Kiemnec et al. (1990) reported sweet corn yields were similar between $(NH_4)_2SO_4$-treated soil and biosolids-treated soil.

Whether soil-N availability explains the yield differences may depend on the crop being studied. Although we did not anticipate that N would affect soybean yield, the correlation between seed yield at R6 and plant available N suggests that N did play a role. Since soybean nodule biomass was inhibited by biosolids to a much greater degree than both MYWC-treated plants, the actual difference in concentration of nitrogen compounds in the rooting zone between the biosolids and MYWC treatments may have been even greater than suggested by Table 2. This hypothesis is supported by the findings of Claassen and Cary (2004) who reported that a biosolids plus yard waste co-compost mixture released more N than a yard waste compost alone.

Conversely, N is not normally considered a fertility requirement for inoculated/nodulated soybean in Texas and nodules were numerous in the check plots, suggesting appreciable N_2 fixation was likely to have occurred. Therefore, it may not be appropriate to attribute the biosolids-induced soybean yield increase to N alone. Regardless, the soybean responses reported here provide indirect evidence that the current soybean fertility recommendation on this particular calcareous soil for both N and non-N elements needs to be revisited.

A strong correlation between turnip root yield and plant available N in the soil was also found suggesting that N was a primary element limiting yield in the unfertilized turnip plots. Although it is likely than the increased plant available N in the amended plots had something to do with the increased beet and sweet corn yields, these two traits were not correlated. Therefore, nutrients other than N may have been the primary cause of their yield responses. Our observations, especially with biosolids, raise the possibility that lower application rates might be warranted. The plant available N (287 and 264 lbs ac^{-1} applied in 2001 and 2002, respectively) resulting from biosolids might likely be considered excessive depending on the crop to be grown. Regardless, a reduced biosolids rate (lower than 11.6 tons ac^{-1}) should be researched in future studies.

The availability of other elements such as P in biosolids (0.86 – 1.22%) and K in the MYWC (0.33 – 0.38%) may have also played a role in our results. However, Bierman and Rosen (1994) reported that yield response of sweet corn to P from triple superphosphate fertilizer was equal to or better than P from sewage-sludge ash. In the case of our vegetable soybean, pretreatment soil test results did not indicate non-N mineral nutrient deficiencies in the control plots. Mehlich-3 extractable P level was 18 ppm, which is in the middle sufficiency range for soybean as recommended by the Texas Cooperative Extension Soil Water and Forage Testing Laboratory.

Our biosolids findings, and to a lesser extent our results with the high rate of MYWC, raise at least two additional ideas. First, biosolids and MYWC may have contributed an excellent balance of nutrients required for these four vegetable crops, a balance that might be difficult to mimic with synthetic fertilizer. Bañuelos et al. (2004) found that total and water extractable essential plant nutrients (N, P, K, S, B, Cu, Zn) were increased in the 0 - 6 in soil depth following two years of biosolids applications at rates less than half the rate used in our study. Bierman et al. (1995) reported that ash from sewage sludge increased pH and soil Zn concentration. Zinc and Cu are frequently limiting in the calcareous soil used in our study. Heitholt et al. (2002) found that application of Cu to this soil type (and to a lesser extent Zn application), increased fruit yield (seed plus pod walls) of greenhouse-grown soybean. In strawberry, soil-applied composted municipal sludge or composted yard waste showed minimal effect on plant fresh weight (Funt and Hummell 1996). However, both amendments reduced leaf tissue Fe concentration. Clearly, further experiments with the species used in our study comparing biosolids, MYWC, and selected blends of inorganic elements on a calcareous soil are needed to confirm whether or not a conventional fertility program could have achieved the yields obtained by the biosolids and compost treatments.

Although soil nutritional changes due to the amendments are likely to be a primary factor related to the yield increases observed from the soil-applied biosolids and MYWC-High treatments, we must mention other factors. Although not measured here, possible changes in soil bulk density, soil gas exchange, or root-soil water relations could have contributed to our growth observations. Because soybean leaf relative water content was similar among treatments in our study, we cannot support the idea that biosolids improved plant water relations.

CONCLUSIONS

Our results indicated that vegetable crop yields on this calcareous soil can be markedly increased by adding biosolids or slightly increased by adding MYWC. Depending on the crop, yield increases are most likely due to increased plant available N, P, and K but trace nutrients supplied by the organic matter treatments cannot be ruled out. The yield increase for soybean was associated with increased shoot-to-root ratio, harvest index, and overall biomass production. For beet and turnip, the biosolids-induced yield increase was associated with an increase in biomass. The corn ear yield increase from biosolids was associated primarily with a higher harvest index and weight per ear but total biomass was also important. Even though Hemphill et al. (1982) and Dixon et al. (1995) reported little change in heavy metal concentration in the edible portion of their vegetable products, we acknowledge that many consumers are still likely to reject produce grown on biosolids-treated soil. However, we suggest that a biosolids treatment might be included as a standard treatment in future fertility research in order to identify soil amendments that will optimize vegetable production on Blackland soils in north Texas.

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